3200 line spectrum ...
when shouldn't you use it?

If you need to resolve vibration frequency components that are closely spaced, the 3200 line spectrum may be the answer. The time required to sample the data, though, could lead to problems that prohibit its use in many practical circumstances.

More lines do not mean more power

The 3200 line spectrum seems to be popular because large numbers equate to speed and power. There are a few very rigid rules, though, that apply to acquiring data for a spectrum that indicate just the opposite. These rules (see sidebar, Universal laws and digital sampling, on page 18) can be summarized with the statement "You can't get something for nothing!" More specifically, when you ask for more resolution in your spectrum, you pay the price in longer sampling times. The increased time needed to sample the data limits when you should apply the high resolution spectrum.

Comparing the 3200 and 400 line spectrums

Let's look at two examples of applications where the 3200 line spectrum might be used. We will compare the sampling characteristics (resolution, sample time, sample rate, and frequency span) with those when a 400 line spectrum is used to see what the consequences are to the data acquisition process. We will do the sampling asynchronously rather than synchronously for simplicity. It is the nature of the data and the application that determine which method will be used, but the same rules apply to both methods. The values will be computed using the equations in the sidebar.

Example 1

An induction motor has a line frequency of 3600 cpm and a full-load speed of 3560 rpm. In order to resolve running speed from line frequency, the frequency interval between lines of the spectrum Δf should be no more than 40 cpm or 0.66 Hz. For a 3200 line and a 400 line spectrum, the values in Table 1 can be derived from the rules of sampling.

	3200 lines	400 lines
Resolution Δf	40 cpm	40 cpm
Sample time T	1.5 seconds	1.5 seconds
Sample rate	5.5 kHz	680 Hz
Frequency span	2.1 kHz (36X)	267 Hz (4.5X)

Table 1. Comparison of 3200 and 400 line spectrum sample rate and frequency span based on 40 cpm resolution between lines.

Notice that, once the resolution is determined, the sample time is also determined, regardless of the number of lines. The relationship of the other values for the two cases is the same as the ratio of the number of lines: 8 to 1. This makes it easy to see what the effects of higher or lower resolution are once one set of values has been computed.

Which one works? While it would appear that both resolutions would be able to resolve the components, the following practical considerations must be taken into account:

• Frequency span scale on the spectrum display. If your display uses the standard 1 - 2 - 5 multiplier sequence (10, 20, 50, 100, etc.), then the frequency span will have to be decreased, increasing the resolution and sampling time slightly.

• Resolution of components. If you really want to resolve the components distinctly, then the resolution you pick should be at least half (possibly one third) the separation between the components. This is because, digital or not, the display still acts as though it has an

	3200 lines	400 lines	3200 lines
Δf	17 cpm	15 cpm	3.4 cpm
T	3.5 seconds	4.0 seconds	17.5 seconds
Sample rate	2.56 kHz	256 Hz	512 Hz
Frequency span	1 kHz (17X)	100 Hz (1.7X)	200 Hz (3.4X)

Table 2. Comparison of 3200 and 400 line spectrum sample time and sample rate based on acceptable resolution and standard frequency span. Note sample time for 3200 line spectrum if frequency span is selection criterion.

analog filter on the front end, and the filter is not perfect. For this example, let's change the frequency span (the usual way to change resolution when you want to keep the number of lines fixed) and, consequently, the resolution and sample time. Notice that by selecting a frequency span based on the standard scaling (Table 2), we've changed the resolution and sample time values by more than a factor of two. Note the 17 second sampling time if we apply the 3200 line to a more reasonable frequency span, just over 3X rotative speed.

The result is that the 3200 line spectrum, although covering a much wider span than is necessary (17 orders), is the most likely to give you the desired results, *theoretically*. But in the next section, Practice versus theory, we shall see that it is not always practical and appropriate.

Example 2

An induction motor is driving a compressor through a speed increasing gearbox. Input speed for the motor during overspeed test is 1963 rpm; output speed is 7253 rpm. For a 133 tooth gear (and 36 tooth pinion), the gear mesh frequency is 261 kcpm (4.35 kHz). If we look at a frequency span that includes 3 harmonics of the gear mesh frequency, the frequency span of the display will be set at 20 kHz (1,200 kcpm).

In this example, a "ghost" frequency, produced by improper grinding, appears at just over 2X mesh frequency, with sidebands at multiples of running speed,1963 cpm. Let's see if a 3200 line or a 400 line spectrum will resolve the sidebands (Table 3).

Once again, it would appear that the 3200 line spectrum lets us accomplish the task we set out to do. But will the practical considerations limit its application?

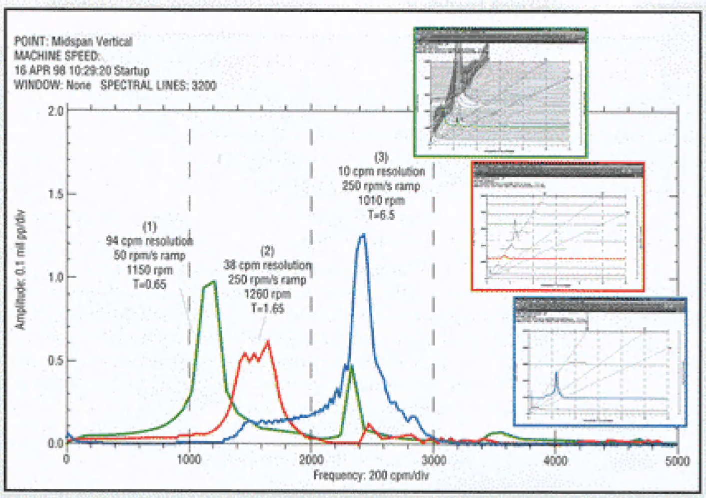

Figure 1. Examples of smearing. Speed change during sample time: 1) 30 rpm (baseline); 2) 400 rpm (moderate smearing); 3) 1500 rpm (extreme smearing).

	3200 lines	400 lines
Δf	375 cpm	3000 cpm
T	0.16 seconds	0.02 seconds
Frequency span	20 kHz	20 kHz
Sample rate	51.2 kHz	51.2 kHz

Table 3. Comparison of 3200 and 400 line spectrum resolution and sample time based on frequency span.

Practice versus theory - pitfalls

One very important consideration when acquiring data for a spectrum is the change in frequency during the sample time, which can cause smearing. Whenever the frequency changes, both the accuracy of the amplitude and the frequency are affected. The amplitude is reduced, and the frequency is smeared, or spread out, over a wider span. It is sometimes even shifted by a significant amount.

This effect is greatest, but not always obvious, when capturing data from a rapid startup or shutdown. It is also a problem whenever the operating speed is fluctuating, such as with a steam turbine driver. The greater the speed change during the sample time, the greater the smearing (Figure 1).

Let's return to Example 1 to see what would happen if we tried to take a 3200 line spectrum during the startup of this induction motor, which takes 18 seconds. If we assume a linear acceleration of 200 rpm per second, then, during each sample record, the motor will change its speed by 700 rpm .

3600 rpm/18s = 200rpm/s

3.5 s/record x 200 rpm/s = 700 rpm/record.

Compared with a resolution of 17 cpm, we can see the *considerable potential for smearing of the spectrum* — smearing that might not be obvious and that could definitely lead to a misdiagnosis. The frequency span for the 3200 line spectrum would have to be increased considerably in order to reduce the sample time, reducing its resolution, and completely eliminating its advantage over the 400 line spectrum.

But does smearing apply to *Example 2*? While an induction motor does not change operating speed significantly, what if the train used a steam turbine driver? If the steam turbine varies speed by just 20 rpm (1%), then the compressor varies its speed 85 rpm. This is not significant. But what about the gear mesh frequency of the gearbox? A one percent change in the gear mesh frequency amounts to 2600 cpm, 5200 cpm in the 2nd harmonic. Even

though the sample record time for the 3200 line spectrum is only 0.16 seconds, smearing of the spectrum will obliterate the information.

Another pitfall is the fewer number of 3200 line spectrums that are displayed during a particular period. For the same frequency span, there are 8 times as many 400 line spectrums displayed as 3200 line spectrums. The increased number of 400 line spectrums can help the analyst accurately pinpoint transient conditions and correlate them to changing process and vibration conditions.

400 line spectrum optimum for majority of jobs

Electric motor and gearbox diagnostics that require the 3200 line spectrum make up a small part of the jobs that our Machinery Management Services (MMS) group is involved in. They typically use a default setting of 400 lines and a span of 10X rotative speed (for undocumented machines), or 4-5X rotative speed otherwise, unless there are special circumstances. Their rule of thumb to prevent smearing of the 400 line spectrum is to set a threshold of 6 to 7 seconds for a train to come up to 1800 rpm. If it takes more than 7 seconds to come to speed, the potential for smearing is small. If it takes less time, a more traditional method of data acquisition is used, the analog tape recorder. This allows the speed of the machine to be slowed, for the data acquisition process, so an accurate sample may be acquired. It also allows the signal to be sampled at different resolutions without additional runs of the machine. Note that, once a signal is digitally sampled, the resolution cannot be increased without re-sampling, a problem that is solved with the tape recorder.

If you have XY transducers, be sure to use the full spectrum, which provides additional information about the direction of vibration precession and orbit shape.

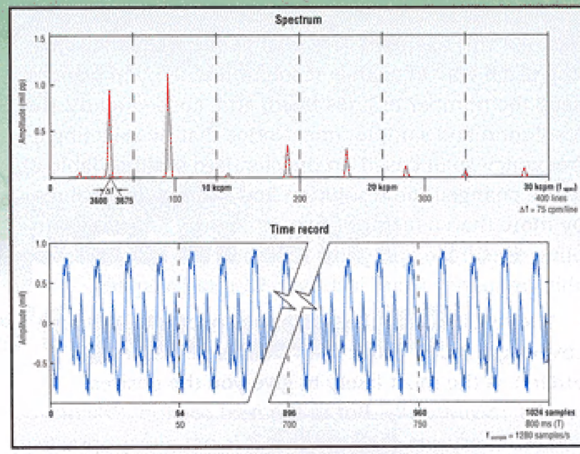

Figure 2. A sampled time domain waveform and its half spectrum in the frequency domain.

See page 23 for the article *Toolbox Tips - When you use spectrum, don't use it halfway* for a more complete description of the full spectrum and its advantages.

Plan ahead

Obviously, any changes in the speed of the machine while data is being acquired, must be considered when selecting the appropriate number of lines and resolution (sampling time) for the spectrum display. The 3200 line spectrum is appropriate in some circumstances, but, before it is applied, a more powerful analyzer must be used, the human brain. Use the relationships shown in Figure 2 and the sidebar to help give you confidence in the information you take and the decisions you make.

If you have any questions, contact the Machinery Management Services Engineer at your nearest Bently Nevada office.

Universal laws and digital sampling

There are three universal laws which deal with digital sampling of waveforms and computation of spectra using the Fast Fourier Transform (FFT).

1. The frequency response (span) determines the minimum sample rate
2. The total sample time (sample record length) determines the resolution
3. The number of samples governs the number of lines in the spectrum

1. If you know the highest frequency in your signal, or the highest frequency you want to measure, then the signal must be sampled at at least twice this frequency (the Nyquist criteria). In fact, asynchronous sampling is most often done at 2.5 to 3 times this frequency. A low pass filter is then used to prevent aliasing, the mirroring of higher frequencies into the spectrum. The upper portion of the spectrum, that may have aliases (since the filter is not ideal), is then discarded.

$$f\ \text{sample} = 2.56\ f\ \text{span}$$

2. The resolution Δf, or spacing between spectrum lines, is the reciprocal of the length of time you sample T:

$$\Delta f = 1/T$$

$$\text{lines displayed} = f\ \text{span}/\Delta f$$

Simply stated, to know more about the frequency content, we must take more time to sample.

3. The number of time domain samples determines the number of frequency domain samples. However, for the half spectrum, half the samples are mirrored about the origin as negative values. These samples do not contain any new information, and are discarded. Thus, a 1024 time domain sample produces a 512 line half spectrum. For asynchronous sampling, the top 112 lines are discarded, and the remaining 400 are displayed.

$$\text{Samples}/2 = \text{lines}$$

$$\text{Lines}/1.28 = \text{lines displayed}$$

Reference:

Southwick, D., "Sampling waveforms and computing spectra," Orbit, September, 1993, Bently Nevada Corporation.